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## GEOLOGY OF THE HAYSTACK STOCK, COWLES, PARK COUNTY, MONTANA

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### INTRODUCTION

The Haystack stock is a mass of coarse-grained gabbro, diorite, and allied rocks, situated at the head of Boulder River, near Cowles Post-Office, Park County, Montana, in the southeastern quarter of the Livingston quadrangle, about 65 miles by stage from Livingston. The geology of this portion of the Livingston quadrangle was mapped in 1890 by Professor J. P. Iddings, but the Haystack stock, and its relations to the surrounding rocks, were regarded by him as of sufficient interest to warrant further study, and, accordingly, in 1903, additional field-work was done by the writer, assisted by Robert Butler, A. C. Ellsworth, and James Walker. No claim for originality is made for the geological map, Fig. 1, since it is essentially that published in the Livingston folio. Mr. Iddings further directed the office work, and placed in the hands of the writer his field notes and a large amount of material collected during the mapping of the Livingston quadrangle. Analyses of six type specimens, and of two mineral separations were made in the laboratory of the U. S. Geological Survey by Mr. George H. Steiger.

### PHYSIOGRAPHY

*Topography.*—The area included within the limits of the map, (Fig. 1), is a part of the high dissected plateau which is somewhat indefinitely called the Snowy Mountains. The general elevation of

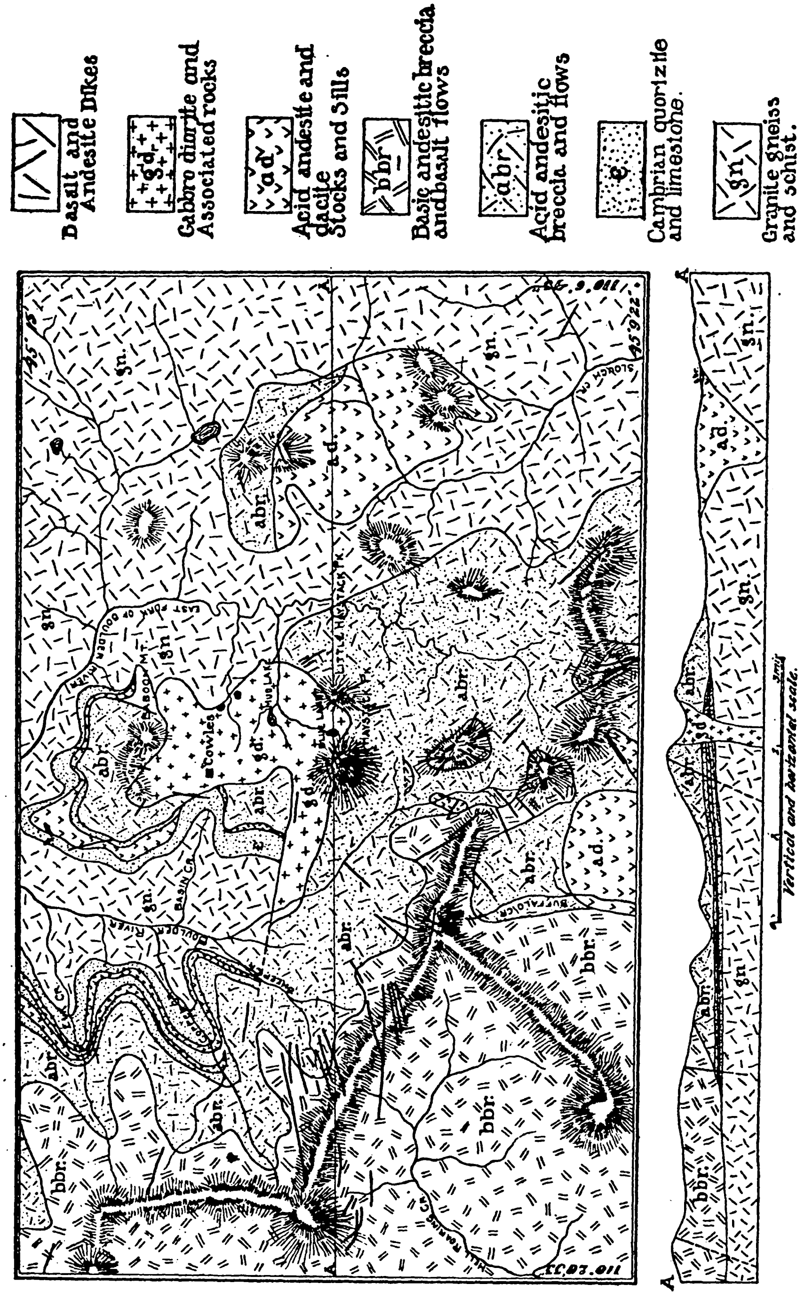


FIG. 1.—Map of Haystack stock and vicinity, Cowles, Park Co., Mont.

this plateau is from 9,000 to 10,000 feet above sea level and numerous peaks are higher. Of these the most conspicuous are Haystack Peak, Little Haystack Peak, and Baboon Mountain. Many canyons traverse the plateau and are sunk from 2,000 to 3,000 feet below the level of the upland. They are narrow, U-shaped, and their walls are very steep, even to the sources of the streams. The trees are mainly spruce, white bark pine, and lodge-pole pine. They are comparatively small and are valuable only for local use in connection with the nearly dormant mining industry. Aspens and willows grow in the marshes along the streams, and above 9,500 feet the vegetation consists chiefly of small junipers and stunted cedars.

*Drainage.*—The Boulder River is the most important stream of the area; rising south of Haystack Mountain it flows northward through the Snowy Range and enters the Livingston River at Bigtimber. Several tributaries join the Boulder River from the west, among which are Elk Creek, Copper Creek, and Sheep Creek. From the east its affluents are East Fork and Basin Creek. The southeastern portion of the area mapped is drained by Slough Creek which, flowing southward, joins the Yellowstone River in the Yellowstone National Park. Haystack Basin lies between Haystack Peak and Baboon Mountain. A low ridge, trending north and south, forms a watershed west of which the drainage is through Basin Creek into the Boulder River.

*Effect of character of rocks upon topography.*—The stock of Haystack Basin, especially the coarse-grained central portion, weathers very readily, falling into coarse arkose and consequently forms a relatively low area. The eruptive rock around the stock is very resistant, since it has been indurated at the contact and it forms the mountain crests to the north and to the south of the basin. Elsewhere, the breccia and minor intrusives appear to have been eroded at about equal rates. Dikes seldom stand out conspicuously above the surface, and other intrusives, aside from the Haystack stock, do not find marked expression in the topography. Sedimentary rocks have only a small areal distribution. They are nearly flat and do not form notable physiographic features. They outcrop only on the sides of the canyons and are represented by a quartzite member which usually forms a bench, above which is a ledge of limestone.

The differences in the constitution of the crystalline schists are too slight to find expression in topographic form.

*Glaciation.*—The effects of glacial erosion are conspicuous in the Snowy Mountains. The streams head in typical glacial amphitheaters, sharp and clear cut. On the floors of these amphitheaters in rock basins are occasional lakes. In this part of the valleys drift is thin or absent and at many places the rocks are polished or striated. Lower down in the mountains, usually three or four miles below the sources of the streams, the floors of the canyons are covered with drift which at many places occurs as knobs or hillocks from ten to forty feet high. Lakes and kettles within the morainal belt are comparatively rare.

*Culture.*—In some years a five-stamp mill is operated at Cowles Post-Office during a part of the summer and a number of prospectors do assessment work. As soon as the snow becomes too deep for easy travel, the country is almost deserted until the following spring. A wagon road connects Livingston with Cowles. From there trails lead southeast to Cook City and to the mines around Horseshoe Mountain. In the early 90's this area was the scene of considerable mining excitement, and a camp of a hundred or more houses, known as Independence, was built at the junction of Basin Creek and Boulder River. A mill was installed at this point and ore was hauled by wagon from the Independence mine in Haystack Basin. The camp was soon deserted, but the name is sometimes used for the camp at Cowles Post-Office, about a mile east of the old camp.

## OUTLINE OF GENERAL GEOLOGY

*Pre-Cambrian gneisses and schists.*—The oldest rocks within this area form a crystalline complex consisting in the main of crenulated and intensely folded granite-gneiss and mica-schist. The gneiss is at most places coarse-grained, though medium or fine-grained facies are common. The gneiss is composed of feldspar, quartz, biotite, and muscovite, with hornblende and magnetite as accessory minerals. Like minerals are arranged in laminae giving the gneiss its banded appearance.

Traversing the gneiss in all directions are streaks of dark mica-schists varying in width from less than an inch to more than fifty

feet. The direction of schistosity agrees closely with the banding of the gneiss, and both were apparently produced at the same time. The dark schists consist essentially of biotite, feldspar, and hornblende. The contacts between the gneiss and the included schists are not sharp and distinct, though a short distance away they appear to be so, owing to the contrast in color between the light and dark rock. The two merge into each other within a narrow zone, and the bands of schist thin out and end within the gneiss. The forms assumed by the bands of schist are extremely irregular; some of them are curved lines; sigmoidal forms are not uncommon; rectilinear bands do not occur for any considerable distance. Some of the curved bands are fractured and broken by faults which have been completely healed.

*Pegmatite.*—The crystalline complex is cut by dikes of pegmatite which is composed of feldspar, quartz, and mica. Such dikes are especially well developed on Lake Plateau about two miles north of the northeast corner of the area mapped (Fig. 1) where red feldspars occur in large crystals which inclose smaller bodies of quartz, most of them about two inches in longest dimension, and thick six-sided plates of mica about half as large. The pegmatite is not mashed and, therefore, is later than the metamorphism of the gneiss and schist, but since it does not cut the Cambrian sediments it is probably of pre-Cambrian age.

## CAMBRIAN

Overlying the pre-Cambrian rocks unconformably are beds of Cambrian quartzite, limestone, and shale. The basal member is a buff, pink, or gray quartzite from 200′ to 300′ thick, and its basal layers at some places contain small pebbles of the crystalline schists. The quartzite is thoroughly indurated, and under the microscope shows characteristic secondary enlargements of the grains of quartz.

Above the quartzite and conformable with it in dip is blue or gray limestone from 50′ to 300′ thick, near the base of which are a few feet of shale. It is sometimes massive, more often thinly bedded, and contains cherty layers. Some of the layers of the limestone are limestone conglomerate, composed of flat limestone pebbles from

one-half inch to five inches in diameter, cemented by a limestone matrix. The limestone has been extensively recrystallized since it was deposited and is largely composed of closely interlocking anhedrons of calcite, 1 $^{mm}$ or less in longest diameter. In some localities it is rich in fossils. On the trail about two miles northwest of the point where Boulder River is intersected by the northern boundary of the area mapped on Fig. 1, exposures show that certain beds of the limestone are composed almost entirely of fragments of trilobites. The quartzite is the Flathead quartzite of Mr. Weed[1] and the limestone is very probably to be correlated with the Meagher limestone in his section at Helena.[2]

Immediately south of Copper Creek, at a point about three-quarters of a mile above its junction with the Boulder River, the limestone, here thinly bedded and shaly, rests upon gneiss, showing that it was deposited by overlap upon the sinking Cambrian sea bottom.

The Cambrian beds dip gently west-southwest away from the pre-Cambrian rocks and are intruded by sills of andesite-dacite, and cut by the Haystack stock. At the contact with the stock the limestone is metamorphosed and locally contains secondary quartz, epidote, garnet, and an undetermined amphibole. The attitude of the Cambrian beds at the contact with the Haystack stock is approximately the same as away from it.

## EXTRUSIVE ROCKS

*Occurrence and distribution.*—Overlying the crystalline schists and the sedimentary rocks and conforming to the irregularities of their eroded surface is a great thickness of extrusive rocks, consisting of breccias, tuffs, agglomerates, and lava flows. These rocks are formed of material thrown out of volcanic vents and are more or less continuous for many miles to the south and west, covering a vast area in and around the Yellowstone National Park.

The extrusive rocks do not represent a continuous series, for unconformities of erosion occur at many places. The presence of silicified trunks and stumps of trees, some of them upright as they grew, shows that between the volcanic eruptions there were periods of

[1] *Livingston Folio,* Geological Atlas of the U. S., U. S. Geological Survey.

[2] *Helena Folio,* Geological Atlas of the U. S., U. S. Geological Survey.

quiescence of considerable duration. At some of these unconformities there is an abrupt change in the appearance of the breccia. There are more or less constant differences between the lower and the upper portions of the breccia, and the series has been divided by Mr. Iddings[1] into the acid andesitic and the basic andesitic breccia.

*The acid andesitic breccia.*—The acid andesitic breccia consists chiefly of light-colored andesite, dacite, and latite fragments which vary in size from fine dust to masses several feet in longest dimensions. The coarse material is most abundant in the lower portion of the formation, while the upper portion contains beds which are composed almost entirely of volcanic dust. The chaotic basal portion contains large fragments of gneiss and quartzite, which were broken from the pre-Cambrian and Cambrian formations, and probably represent material thrown out at the time of the earliest eruptions. Such fragments are very abundant in the west wall of the Boulder Canyon due west of Haystack Peak.

The upper portion of the acid breccia is largely composed of fine material; some of it is well stratified but probably of subaerial origin. The bedded tuffs dip at low angles but the dip is not quaquaversal with respect to the Haystack stock. It is probable that the material from these beds came from several sources, and since much of it is very fine, the sources may have been a considerable distance away. The thickness of the lower acid breccia is variable and reaches a maximum of 1,500 feet. It is well exposed above the Cambrian on the divides between the tributaries of the Boulder River at the head-waters of this stream, also south of Haystack Peak at the head of East Fork, and at the head of the drainage of Buffalo Creek. There is an isolated remnant of the breccia capping the gneiss about two miles northeast of Little Haystack Peak. The acid breccia probably once covered a much more extensive area than it does now, and has since been eroded. Mr. Arnold Hague[2] has shown that in the Yellowstone National Park this early acid breccia belongs to the Eocene period and corresponds with the Fort Union horizon. The early acid breccia is cut by andesite-dacite stocks and

[1] Iddings, *Livingston Folio*, p. 6.

[2] "The Age of the Igneous Rocks of the Yellowstone National Park," *American Journal of Science*, Fourth Ser., 1896, p. 450.

by the Haystack stock. At its contacts with the Haystack stock the breccia is greatly indurated and weathers at some places like a massive rock. On account of its greater hardness this contact at most places forms a ridge. Since the border facies of the Haystack stock is fine-grained, it is impossible at many places to locate precisely the contact, though the doubtful zone is usually not more than a few yards wide.

*Basic andesitic breccia.*—The basic andesitic breccia is darker than the acid breccia. Chocolate, dark grays, and somber shades of red and yellow predominate. It is composed of pyroxene-andesite and hornblende-pyroxene-andesite, with a subordinate amount of dacite and latite. Fragments of gneiss or of quartzite are much less abundant than in the lower breccia. The fragments are generally smaller than those in the basal portion of the acid breccia and beds of fine-grained tuff are less conspicuous than in the acid breccia. Basaltic lava flows which are very common, especially near the top of the formation, are best developed in the southwest portion of the area. The thickness of the upper breccia is very great. The canyon of Hell Roaring Creek, several miles southwest of the area mapped, is nearly 3,000 feet deep and is cut entirely in this formation. It is probable that this breccia also was formerly more extensive and it may have completely covered the acid breccia. The basic breccia is of Neocene age.[1]

ANDESITE-DACITE INTRUSIVES

*Andesite-dacite sills.*—Andesite-dacite sills occur as sheets injected between the Cambrian strata. In this area they are present wherever a section of Cambrian rocks is exposed. At most places there is a sheet between the quartzite and the limestone at the horizon of the shales which occur at the base of the limestone and several sheets are intercalated within the limestone. The cartographic representation is necessarily generalized, showing from one to three of these sheets, but where the Cambrian beds are thickest there are sometimes more. The maximum thickness of the sills is about two hundred feet.

The andesite-dacite is dark gray, reddish gray, or brown, and contains phenocrysts of feldspar, hornblende, quartz, and biotite.

[1] J. P. Iddings, Folio 30, "Yellowstone National Park," Geological Atlas of U.S., U. S. Geological Survey.

Under the microscope the groundmass is seen to be microcrystalline and contains phenocrysts of andesine, green hornblende, quartz, orthoclase, magnetite, and biotite. Calcite and serpentine are present as secondary minerals. Orthoclase and quartz are sometimes present in considerable amount when the composition of the rock approaches that of quartz-monzonite-porphyry. Since the sills are cut by the Haystack stock they are older than it, and since they do not cut the breccias they are possibly older than them, and presumably the oldest Tertiary volcanics in the district.

*Andesite-dacite stocks.*—Andesite-dacite stocks cut the pre-Cambrian rocks and the basic breccia. The largest one is about two miles east of Little Haystack Peak, and covers an area of nearly two square miles. Several smaller bodies occur along the southern border of the area mapped.

The andesite-dacite is gray or pinkish gray, and contains phenocrysts of feldspar, hornblende, quartz, and mica. Under the microscope the groundmass is seen to be microcrystalline and contains phenocrysts of andesine, quartz, green hornblende, pyroxene, orthoclase, and magnetite. The andesite-dacite stocks are younger than the early breccia and probably older than the later breccia. They are closely allied to the sills in composition, but if the sills are older than the early breccia, which the stocks cut, a considerable period intervened between the two intrusions. The composition of the andesite-dacite is near that of the early breccia, and the sills, stocks, and breccia probably came from the same or closely related magmas.

*The Haystack stock.*—The Haystack stock is an intrusive body of irregular shape cutting through pre-Cambrian schists, Cambrian sedimentary rocks, and the early acid breccia. It is composed entirely of granitic rocks varying in composition from quartz-monzonite to olivine-gabbro. These grade into one another, and it is assumed that they represent the products of differentiation from a common magma.

*Basalt and andesite dikes.*—Basalt or andesite dikes cut all the other rocks. They are most abundant in the country south, west, and east of the Haystack stock, and have a rudely radial arrangement around it. In width they vary from four inches to forty feet and some are exposed for considerable distances, though most of them

are partially concealed by detrital material. In appearance the dike rocks are dark and either aphanitic or contain inconspicuous phenocrysts of augite, feldspar, and olivine. Under the microscope they show a considerable range of composition. The basalt dikes have a microcrystalline groundmass containing a large number of lath-shaped labradorite crystals which flow around larger phenocrysts of augite and olivine. Hornblende phenocrysts are present in some thin sections. In the less basic dikes, the andesites, the groundmass, sometimes glassy, contains a smaller amount of plagioclase and augite. Hornblende is more abundant than in the basalt dikes. Some thin sections show numerous large andesine phenocrysts. Some of the dikes can be traced into the Haystack stock, though none of them crosses it. Probably many of them are connected with it in depth.

### PETROGRAPHY OF HAYSTACK STOCK

*Relation to other rocks.*—The Haystack stock occupies the greater part of Haystack Basin, extending eastward nearly to the East Fork of the Boulder River. A long arm trends westward from Haystack Peak for nearly a mile and crosses the West Fork of the Boulder River; another arm extends northwest to the western spur of Baboon Mountain. Its outcrop altogether occupies an area of about two and one-half square miles. The stock cuts through the crystalline schists, the Cambrian sedimentary rocks with intruding sills, and the early acid breccia. There is no evidence that the Cambrian beds were turned up by the intrusion, for wherever they outcrop near the stock, their attitude is approximately uniform and they dip southwestward at low angles near the stock in the same manner as at some distance away from it.

The western arm of the stock is closely related to a fault which extends westward from the north spur of Haystack Peak and crosses the Boulder River at an elevation of about 7,900 feet. North of the fault the Cambrian sediments occur some 600 feet above the stream bed on both sides of the Boulder River. South of the fault the Cambrian is wanting and the breccia is the lowest formation exposed. The minimum throw of the fault at this point is 600 feet. So far as known, the Haystack magma did not penetrate the shaly beds between

the Cambrian quartzite and the limestone. The sills in the Cambrian are characteristic of this formation over wide areas and are not to be regarded as apophyses of the Haystack stock; further, they are more siliceous in composition than the average of the stock, and they are thicker away from the stock than near it.

There is no conclusive evidence that the Haystack stock ever reached the surface. It is of later age than the acid breccia, and appears to have extended to near the top of this formation, but it may have been deeply buried under the basic breccia, which has a thickness of 2,000 feet or more in Hell Roaring Creek near by. Since, however, its composition is near that of the basic breccia, it is possible that it formed a channel through which a portion of this breccia reached the surface.

*Appearance.*—The peripheral facies of the Haystack stock is dark, fine-grained, and contains a few inconspicuous anhedra of feldspar and biotite. A short distance toward the center from the periphery, it becomes of lighter color and coarse grain, and is composed of feldspar, quartz, hornblende, and mica. Still farther from the border, it becomes much more coarsely crystalline, of darker color, and is composed of biotite, pyroxene, and magnetite. In the more basic facies of the central portion of the stock the ferro-magnesian minerals approximately equal the light-colored constituents. The various facies grade one into the other except in rare cases where locally there is a rather sharp contact between them. A notable example occurs near the wagon road a few rods south of the divide between West Basin Creek and East Basin Creek, where dark gabbro of medium grain appears to cut the coarser, lighter gabbro, but a few feet away from this contact these two rocks, traced continuously between, grade into each other as elsewhere. The various rocks of the stock are always massive, and do not show evidence of mashing. Near the border a few fragments of surrounding rocks are present, but these are rare or wanting in the interior of the stock. There has been fracturing since the solidification of the stock and it is traversed by joints in several directions. Along some of these fractures the surrounding rock is extensively altered, but this alteration is local and the rocks of the stock are for the most part fresh.

At a number of localities veins of coarse-grained granite cut the

stock. These vary in width from less than one inch to six or eight inches, and contrast strongly in color and composition with the surrounding rock. Basalt and andesite dikes which are exposed at numerous places a short distance from its border do not cross the stock, nor do they occur near its center.

*Minerals of the stock.*—The constituent minerals of the stock, though all are not present in a single specimen, in approximate order of abundance are: plagioclase, orthoclase, augite, hypersthene, biotite, quartz, hornblende, magnetite, olivine, apatite, pyrite, and zircon. Plagioclase shows the usual albite and carlsbad twinning, and frequently zonal structure. Some of the plagioclase contains a large number of minute dark inclusions, which give it a grayish color. Small prisms of apatite, together with a few anhedrons of ferromagnesian minerals are similarly included. In composition the plagioclase varies from oligoclase to labradorite. In the diorite and quartz-diorite plagioclase is as a rule oligoclase or andesine, and in the most basic types it is labradorite. The total amount of plagioclase in the different rocks of the stock is remarkably uniform, and in most instances it constitutes from 40 per cent. to 50 per cent. of the rock. Plagioclase was among the first minerals formed.

Orthoclase, always present, and in some specimens in considerable amount, forms irregular anhedrons which fill the interstices between all the other minerals, except quartz. Some of it incloses ferromagnesian minerals, and apatite; and again it incloses plagioclase poikilitically or is microperthitic with albite. It was one of the latest minerals formed, and constitutes from 2 to 18 per cent. of the rock. Quartz occurs as irregular bodies in nearly all of the rocks of the stock, though it is wanting in some of the olivine gabbros. It reaches a maximum in the granodiorites, where it constitutes nearly 20 per cent. of the rock. In many specimens quartz and orthoclase form a micrographic intergrowth in which orthoclase exceeds quartz. The micrographic intergrowth crystallized after all other minerals had formed.

Pyroxene, though not present in every facies of the stock is, altogether, the most abundant ferromagnesian mineral. Its anhedra are for the most part irregular, but some of them approach idiomorphism. Augite and hypersthene are both present. Augite is pale violet.

buff, and is very faintly pleochroic. It is twinned parallel to the first pinacoid. Hypersthene is rather irregular in outline, is never twinned, and is less well cleaved than augite. The pleochroism varies from pale green parallel to $\mathfrak{c}$ to reddish yellow parallel to $\mathfrak{a}$ and $\mathfrak{b}$. The two pyroxenes are intricately intergrown and were synchronous in their crystallization which was, in some cases, contemporaneous with and in others immediately followed that of plagioclase. Some of the pyroxene is altered to bastite. An analysis of a mixture of the two pyroxenes from the olivine-gabbro (variety E) is given on p. 215.

Biotite is present in all varieties of the rock and occurs as irregular flakes of various sizes up to $2^{mm}$ in diameter. Biotite incloses small grains of magnetite and more rarely minute bodies of plagioclase; in many specimens it constitutes about 5 per cent. of the rock. An analysis of biotite separated from variety D is given on p. 213.

Hornblende occurs as small irregular anhedrons longer than they are wide; nearly all are fibrous, only a few sections showing the usual hornblende cleavage. It is pale-yellowish green and slightly pleochroic. A part of the hornblende is probably secondary and it may be uralite, though there is nothing in its crystal form to suggest derivation from a previous pyroxene, and it is possible that it is secondary to another hornblende. Minute inclusions of magnetite are present in the hornblende and small shreds of biotite are similarly included, Many of the rocks of Haystack Basin contain no hornblende at all, but it is the chief ferromagnesian mineral of the quartz-diorite.

Magnetite is present in all specimens constituting from 2 per cent. to 5 per cent. of the rock. It is a little more abundant in the more basic gabbros and occurs both as irregular anhedrons and idiomorphic crystals. In feldspar it is present as minute dust-like particles and also in larger bodies, but the greater portion of it is included in or associated with the ferromagnesian minerals. The chemical analysis of the rock shows that it contains considerable titanium. It crystallized partly after the plagioclase and contemporaneously with the ferromagnesian minerals.

Olivine, for the most part allotriomorphic, is present in a few of the more basic varieties of the gabbros. It is fractured and along the cracks is altered to serpentine. Some of it is completely replaced

by the serpentine, and the serpentine includes minute bodies of magnetite. In all the rocks containing olivine a portion of it occurs in small, rounded, oval, or irregular inclusions in the pyroxene, and in specimens where only a small amount of olivine is present all is so included. The quantity of olivine varies from nothing to 5 per cent.

Apatite occurs as slender prisms about $.1^{mm}$ in length, wholly or partially included in the other minerals. In some specimens the prisms are arranged roughly parallel to one another, somewhat analogous to flow structure sometimes exhibited by lath-shaped feldspar in basalts, though the alignment is less perfect. These parallel prisms are included in plagioclase, orthoclase, and in the ferromagnesian minerals, showing that the crystallization of the apatite had begun but that the other minerals had not formed when the magma came to rest. The amount of apatite is nearly uniform and it usually constitutes about 1 per cent. of the rock. Pyrite occurs sparingly except in altered varieties where it is in part secondary. A very small amount of zircon is present in some specimens as characteristic prisms.

## *Description of Types of Haystack Stock*

### VARIETY A. ADAMELLOSE: GRANODIORITE

The most acid part of the stock covers a considerable area on the southern portion of the west spur of Baboon Mountain. It occurs near but not immediately at the edge of the stock. The rock is light gray, medium-grained, and has a smaller percentage of ferromagnesian minerals than any other of the stock rocks, hornblende, magnetite, and biotite constituting less than one-sixth of the mass. It is comparatively homogeneous in composition, although southward it grades into a more basic and more coarsely crystalline diorite.

The pinkish-white feldspar anhedra are from 3 to $5^{mm}$ long and the quartz is of smaller size. Hornblende is the most abundant ferromagnesian mineral, though magnetite and biotite are present.

Under the microscope the texture of the rock is seen to be hypidiomorphic granular. The minerals present in order of abundance are plagioclase, orthoclase, quartz, hornblende, biotite, magnetite, and apatite. Plagioclase occurs in nearly idiomorphic forms, tabular, parallel to the brachypinacoid. Many carlsbad twins and zonally

built crystals are present. Its composition is that of oligoclase-andesine, $Ab_3An_1$.

Orthoclase and quartz are relatively abundant, together nearly equalling plagioclase. Orthoclase, frequently microperthite, occurs as anhedra with a maximum length of $1^{mm}$, and is also graphically intergrown with quartz. It also occurs as zones surrounding crystals of plagioclase. Quartz occurs as anhedra from $0.1^{mm}$ to $0.5^{mm}$ long.

Hornblende forms irregular anhedra, usually about $0.4^{mm}$ long, which inclose a large number of minute bodies of magnetite and biotite. A part of the hornblende, from its fibrous form, is believed to be secondary, possibly to pyroxene, though there is nothing in its outline which suggests the form of pyroxene and it may have been derived from an original hornblende. Biotite occurs as anhedra smaller than those of hornblende. Magnetite is included in the ferromagnesian minerals, and to a less extent in plagioclase. Long prisms of apatite are present. The order of crystallization was as follows: (1) Magnetite and apatite; (2) hornblende and biotite; (3) plagioclase; (4) orthoclase and quartz. The feldspars are slightly altered to kaolin and biotite to a lighter colored mica and to chlorite. An analysis of type A from the west spur of Baboon Mountain (See Fig. 3 p. 222) is given below:

ANALYSIS OF VARIETY A. GEO. STEIGER, ANALYST

| | | | |
|---|---|---|---|
| $Si_2O$ | 65.06 | $H_2O-$ | .31 |
| $Al_2O_3$ | 14.71 | $H_2O+$ | 1.10 |
| $Fe_2O_3$ | 2.82 | $TiO_2$ | .61 |
| FeO | 1.31 | $P_2O_5$ | .18 |
| MgO | 2.48 | MnO | .18 |
| CaO | 3.43 | BaO | .10 |
| $Na_2O$ | 3.86 | SrO | .05 |
| $K_2O$ | 3.48 | Total | 99.68 |

NORM AND MODE OF VARIETY A

The norm of A calculated from the analysis is given in column I of the table below. The mode is given in column II. According to the quantitative classification this rock is adamellose. Its chemical composition closely resembles that of a quartz-mica-diorite, occurring in a stock at Crandall Basin, Hurricane Ridge, Yellowstone National

Park, described by Mr. Iddings.[1] It also resembles that of a hornblende-mica-porphyry from Cliff Creek, West Elk Mountains, Colorado, described by Dr. Whitman Cross,[2] and a mica-diorite from Lippenhof, N. Tryberg, Schwartzwald, Baden, described by Dr. G. H. Williams.[3]

| I. Norm | | II. Mode | |
|---|---|---|---|
| Quartz | 19.50 | Quartz | 22.9 |
| Orthoclase | 20.57 | Orthoclase | 17.8 |
| Albite | 32.49 | Albite | 30.7 |
| Anorthite | 12.51 | Anorthite | 10.3 |
| Hypersthene | 4.80 | Hornblende | 9.7 |
| Diopside | 3.02 | Biotite | 4.2 |
| Magnetite | 3.02 | Magnetite and Ilmenite | 4.1 |
| Ilmenite | 1.22 | Apatite | 0.3 |
| Hematite | 0.80 | Total | 100.0 |
| Apatite | 0.34 | | |
| | 98.27 | | |
| Water | 1.41 | | |
| Total | 99.68 | | |

VARIETY B. HARTZOSE: GRANODIORITE-PORPHYRY

At the eastern edge of the stock about 30 rods north of the wagon road from Cowles to the Yellowstone Park a small tongue extends from the stock into gneiss. The specimen, taken 28 yards south of the northern edge of this tongue, is dark gray, fine-grained, and contains numerous phenocrysts of yellow feldspar, together with a smaller number of phenocrysts which appear from their form to be hornblende, but which in some cases have the luster and cleavage of mica.

Under the microscope the groundmass of the rock is seen to be composed of small interlocking anhedra of poikilitic quartz and alkali feldspar, a large number of minute pyroxene prisms, and a few anhedra of magnetite, plagioclase (oligoclase-andesine), and biotite. The porphyritic bodies, which in hand specimens appear to be crystals of single minerals, are found to consist of several minerals. These aggregations are of two kinds: those composed mainly of feldspar, and those composed mainly of ferromagnesian minerals.

[1] *Mon. XXXII*, U. S. Geological Survey, p. 261, 1889.

[2] *Fourteenth Annual Report*, U. S. Geological Survey, Part II, p. 227, 1894.

[3] *Neues Jahr.*, Band II, p. 624, 1883.

The outlines of the sections of feldspar aggregates are for the most part irregular but some are those of feldspar crystals. They vary from $0.3^{mm}$ to $1.5^{mm}$ in length. The matrix of the feldspar aggregates is mainly orthoclase and included within it are minute bodies of plagioclase, some approaching idiomorphism and showing both carlsbad and albite twinning. They are from 0.1 to $0.2^{mm}$ long, and are oligoclase-andesine. They penetrate one another most complexly. The plagioclase crystals of the aggregates do not lie entirely within the outlines of the orthoclase, but along its edges they penetrate the groundmass of the rock. The amount of plagioclase in the aggregates varies from 10 per cent. to 90 per cent. of the whole, and the quantity of orthoclase is reciprocal with that of the plagioclase. The other aggregates, composed mainly of ferromagnesian minerals, in some cases have outlines which strongly suggest the crystal form of hornblende. These aggregates are composed of mica, pyroxene, magnetite, feldspar, quartz, and apatite, but the proportion of these constituents varies greatly in different cases. In most sections of these aggregates, cut parallel to the *c* axis of hornblende, the minerals are arranged in rows, while in oblique sections and in those cut across the prism, the arrangement, sometimes roughly concentric, is usually quite irregular. The description of a typical section parallel to the *c* axis follows. It is $0.9^{mm}$ long and $0.4^{mm}$ wide, and is composed of mica, magnetite, feldspar, pyroxene, and quartz; mica and magnetite being most abundant. There are four belts parallel to *c* each about $0.1^{mm}$ wide; two of these are composed chiefly of mica, while the alternate two are chiefly magnetite. All the minerals within the aggregate are of small size, though the mica flakes are larger than the anhedra of other minerals. They are in various optical orientations; a little quartz and feldspar are present in all of the belts. Rimming these belts of mica and magnetite is a colorless border consisting of very minute anhedra of feldspar. It is $0.012^{mm}$ wide, and has the outline of a previous crystal. Beyond this is a fringe of minute pyroxene crystals which approach idiomorphism, and interspersed with these there is a small quantity of allotriomorphic feldspar. The inner outline of this fringe is very definite and sharp but the outer border is very irregular. Many of the crystals of pyroxene join the border of feldspar at right angles.

If the pyroxene border is a portion of the aggregate, then its outline is very irregular, but if the inner border of the pyroxene is considered as limiting the aggregate it has a definite crystal form. In other ferromagnesian aggregates rows of magnetite and mica are *en echelon*, and others are composed entirely of magnetite and feldspar, and still others of biotite and feldspar. All of them are surrounded by the fringe of minute pyroxenes.

The magmatic alteration shown by variety B is not unusual in igneous rocks of intermediate composition and is commonly regarded as showing a change in conditions after the phenocrysts formed and before the rock solidified. It is quite possible that some feldspar and hornblende had formed before the lava rose, and that when pressure was relieved they were partially or wholly dissolved, and under the new conditions recrystallized, their elements going into a number of other minerals. The mineral composition of the aggregates is not constant and could not have resulted merely from recrystallization of the original minerals without substitution.

An analysis of B taken from a point near the edge of the stock about 30 rods north of the wagon road from Cowles to the Yellowstone National Park, is given below.

ANALYSIS OF VARIETY B. GEO. STEIGER, ANALYST

| | | | |
|---|---|---|---|
| $SiO_2$ | 64.09 | $H_2O-$ | 0.22 |
| $Al_2O_3$ | 16.20 | $H_2O+$ | 0.44 |
| $Fe_2O_3$ | 2.61 | $TiO_2$ | 0.49 |
| FeO | 2.40 | $P_2O_5$ | 0.24 |
| MgO | 2.06 | MnO | 0.09 |
| CaO | 4.51 | BaO | 0.15 |
| $Na_2O$ | 3.88 | SrO | 0.03 |
| $K_2O$ | 2.51 | Total | 99.92 |

| I. Norm | | II. Mode | |
|---|---|---|---|
| Quartz | 19.20 | Quartz | 21.8 |
| Orthoclase | 15.01 | Orthoclase | 11.7 |
| Albite | 33.01 | Albite | 30.1 |
| Anorthite | 19.18 | Anorthite | 15.1 |
| Hypersthene | 5.82 | Pyroxene | 11.2 |
| Diopside | 2.08 | Biotite | 4.8 |
| Magnetite | 3.71 | Magnetite and Ilmenite | 4.9 |
| Ilmenite | 0.91 | Apatite | 0.4 |
| Apatite | 0.34 | Total | 100.0 |
| Water | 0.66 | | |
| Total | 99.92 | | |

The norm of B calculated from the analysis is given in column I of the above table. This variety is a little lower in silica, potash, and magnesia than variety A, and richer in alumina, ferrous iron, and lime, while it contains approximately an equal amount of soda and ferric iron. Its mode is given in column II of the above table. According to the quantitative classification it is hartzose and in composition closely resembles a granodiorite from Grass Valley, Nev., described by Mr. W. Lindgren.[1] It is also somewhat similar to a granite from Butte, Montana, described by Mr. W. H. Weed.[2]

### VARIETY C. TONALOSE: QUARTZ-BEARING DIORITE

Southwest of the summit of Baboon Mountain and near the outer edge of the stock the rock is fine-grained, dark, and nearly aphanitic, though a few small dark minerals are visible. This rock is cut by small dikes of light-colored medium-grained granite, which are described on p. 223.

Under the microscope the rock is seen to be holocrystalline, and allotriomorphic granular. The minerals, in order of relative abundance are andesine, pyroxene, orthoclase, quartz, biotite, magnetite, and apatite. Andesine, orthoclase, and quartz occur as interlocking anhedra, varying from 0.02 to 0.04$^{mm}$ in diameter and constituting approximately 70 per cent. of the rock. The ferromagnesian minerals are rather evenly spaced with respect to the quartz and feldspar. Pyroxene occurs in bodies from 0.02 to 0.32$^{mm}$ in diameter, those of the smaller size being much the more numerous. The smaller bodies approach idiomorphism, while the larger ones are irregular in form. Both augite and hypersthene are present. Biotite is less abundant and occurs as foliae from 0.1 to 0.3$^{mm}$ long. Magnetite occurs in irregular bodies the size and number of which are something less than those of biotite. Apatite is present as long prisms. The usual order of crystallization was as follows: (1) Magnetite and apatite; (2) Pyroxene, plagioclase, and biotite; (3) Orthoclase and quartz.

An analysis of C, from a specimen taken near the outer edge

[1] *Seventeenth Annual Report*, U. S. Geological Survey, Part I, p. 724, 1896.

[2] *Journal of Geology*, Vol. VII, p. 739, 1899.

of the stock, south of the summit of Baboon Mountain (see Fig. 3) is given below.

ANALYSIS OF VARIETY C. GEO. STEIGER, ANALYST

| | | | |
|---|---|---|---|
| $SiO_2$ | 57.98 | $H_2O+$ | .49 |
| $Al_2O_3$ | 17.01 | $TiO_2$ | .90 |
| $Fe_2O_3$ | 3.34 | $P_2O_5$ | .43 |
| FeO | 3.34 | NiO | trace |
| MgO | 2.74 | MnO | .12 |
| CaO | 7.35 | BaO | .06 |
| $Na_2O$ | 3.92 | SrO | .02 |
| $K_2O$ | 2.02 | Total | 99.86 |
| $H_2O-$ | .14 | | |

The norm of C calculated from the analysis is given in column I of the table below, the mode in column II.

| I. Norm | | II. Mode | |
|---|---|---|---|
| Quartz | 10.38 | Quartz | 12.1 |
| Orthoclase | 11.68 | Orthoclase | 9.7 |
| Albite | 33.01 | Albite | 31.2 |
| Anorthite | 23.07 | Anorthite | 20.8 |
| Hypersthene | 4.71 | Pyroxene | 13.5 |
| Diopside | 8.64 | Biotite | 6.7 |
| Magnetite | 4.87 | Magnetite and Ilmenite | 4.9 |
| Ilmenite | 1.67 | Apatite | 1.1 |
| Apatite | 1.01 | Total | 100.0 |
| Water | 0.63 | | |
| Total | 99.72 | | |

According to the quantitative classification this rock is a tonalose and its chemical composition very closely resembles that of a hornblende-augite-andesite from the Wind River Plateau, Yellowstone National Park, described by Hague and Jaggar,[1] and a diorite from Captains Bay, Unalaska Island, Alaska, described by G. F. Becker.[2] It is similar in composition to a large number of rocks from nearly every continent, being one of the commonest types known. It is very close to Clark's average rock for the United States, but exceeds it slightly in alumina, lime, and titania, and contains a little less magnesia and potash.[3]

[1] *Bulletin No. 168*, U. S. Geological Survey, p. 96.

[2] *Bulletin No. 148*, U. S. Geological Survey, p. 232.

[3] *Bulletin No. 78*, U. S. Geological Survey, p. 37.

VARIETY D. MONZANOSE: QUARTZ-BEARING ORTHOCLASE-GABBRO

Toward the interior of the stock the proportion of ferromagnesian minerals increases and the rock becomes more coarsely crystalline. The specimen described is a grayish-brown gabbro occurring about halfway betweeen Mud and Blue Lakes, and is composed chiefly of feldspar, pyroxene, and biotite.

Under the microscope the following minerals are seen to be present and are mentioned in the order of abundance: plagioclase, orthoclase, augite, hypersthene, magnetite, biotite, quartz, serpentine, and apatite.

Plagioclase occurs in nearly idiomorphic crystals. Carlsbad twins about $1^{mm}$ long are common, and some crystals show zonal structure. Both andesine and labradorite are present. Minute dust-like opaque bodies and larger ones of brown glass, with a little apatite, pyroxene, and magnetite, are included in the plagioclase. Orthoclase and quartz, micrographically intergrown, fill the interstices between other minerals. Augite is more abundant than hypersthene.

Biotite occurs as plates, up to $3^{mm}$ in length, partly altered to hydro-biotite. An analysis of biotite separated from D is given below. Magnetite, highly titaniferous, is included in the other

ANALYSIS OF BIOTITE FROM VARIETY D. GEO. STEIGER, ANALYST

| | | | |
|---|---|---|---|
| $SiO_2$ | 33.07 | $Na_2O$ | 0.28 |
| $Al_2O_3$ | 13.00 | $K_2O$ | 6.11 |
| $Fe_2O_3$ | 17.22* | $H_2O-$ | 5.41 |
| FeO | not det.† | $H_2O+$ | 11.61 |
| MgO | 11.33 | | |
| CaO | 2.45 | Total | 100.48 |

*Contains ferrous iron $P_2O_5$ and $TiO_2$. †Determined as $Fe_2O_3$.

minerals, and is especially abundant in the ferromagnesian constituents. A little serpentinized olivine is present. Long prisms of apatite show a tendency to parallelism. The order of crystallization was as follows: (1) Apatite and magnetite; (2) Plagioclase and the ferromagnesian silicates; (3) orthoclase and quartz. Feldspar is slightly kaolinized, hypersthene is partly altered to bastite, biotite to hydro-biotite, olivine to serpentine. An analysis of D from a specimen taken midway between Mud and Blue Lakes (see Fig. 3) is as follows:

ANALYSIS OF VARIETY D. GEO. STEIGER, ANALYST

| | | | |
|---|---|---|---|
| $SiO_2$ | 54.84 | $H_2O-$ | .34 |
| $Al_2O_3$ | 16.41 | $H_2O+$ | .93 |
| $Fe_2O_3$ | 3.63 | $TiO_2$ | .99 |
| $FeO$ | 4.54 | $P_2O_5$ | .35 |
| $MgO$ | 4.71 | $BaO$ | .12 |
| $CaO$ | 6.64 | $SrO$ | .05 |
| $Na_2O$ | 3.27 | Total | 99.65 |
| $K_2O$ | 2.83 | | |

The norm of D is shown in column I of the following table; the mode in column II.

| I. Norm | | II. Mode | |
|---|---|---|---|
| Quartz | 4.68 | Quartz | 6.8 |
| Orthoclase | 16.68 | Orthoclase | 15.4 |
| Albite | 28.30 | Albite | 27.5 |
| Anorthite | 21.41 | Anorthite | 19.7 |
| Hypersthene | 11.87 | Pyroxene | 19.5 |
| Diopside | 7.32 | Olivine and Serpentine | 0.5 |
| Magnetite | 5.34 | Biotite | 4.6 |
| Ilmenite | 1.98 | Magnetite and Ilmenite | 5.2 |
| Apatite | 1.01 | Apatite | 0.8 |
| Water | 1.27 | Total | 100.0 |
| Total | 99.84 | | |

According to the quantitative system, variety D is a monzonose. It is less siliceous than those previously described and is chemically similar to an augite-andesite-porphyry from the Indian Creek laccolith, Yellowstone National Park, described by Mr. Iddings,[1] and to a diorite from Mt. Ascutney, Vt., described by Mr. R. A. Daly.[2]

VARIETY E. SHOSHONOSE: ORTHOCLASE-GABBRO

This variety occurs about a half-mile northeast of the summit of Haystack Peak and a quarter-mile west of Mud Lake, or about halfway between the western shore of this lake and the north spur of Haystack Peak. It is a dark, coarse-grained gabbro in which feldspar, pyroxene, and biotite are visible in hand specimen, the ferromagnesian minerals constituting about one-third of its volume.

Under the microscope the texture is seen to be hypidiomorphic granular; plagioclase and pyroxene approach idiomorphism; ortho-

[1] *Mon. XXXII*, U. S. Geological Survey, p. 83.

[2] *Bulletin No. 148*, U. S. Geological Survey, p. 69.

clase and quartz are poikilitic with respect to the other constituents. The minerals present in order of abundance are: andesine, augite, orthoclase, hypersthene, magnetite, biotite, quartz, apatite, and olivine.

Andesine occurs in prisms from 1 to $2^{mm}$ long and about $0.3^{mm}$ wide, and commonly as carlsbad twins. Orthoclase occurs as a matrix for plagioclase and the ferromagnesian minerals, filling the angular interstices between them. Quartz is present only as a micrographic intergrowth with orthoclase. Augite, pale violet-buff, occurs as anhedra from 0.5 to $1.5^{mm}$ long. Hypersthene is of the same size and is pleochroic, green parallel to $\mathfrak{c}$, and reddish yellow parallel to $\mathfrak{a}$ and $\mathfrak{b}$. Both pyroxenes contain minute bodies of magnetite, biotite, and apatite, and a little serpentinized olivine, which taken together equal about 2 per cent. of the mineral. An analysis of a mixture of the two pyroxenes is given below. In the preparation of the sample the crushed and sized minerals were separated by Thoulet's heavy solution. The portion of the rock which came down at a specific gravity of 3.1, the maximum specific gravity of the solution, included, besides the pyroxenes, magnetite and bodies composed of magnetite and feldspar or pyroxene and feldspar. Those particles in which there was a considerable proportion of magnetite were removed with the magnet, and the remainder was treated with acid to remove small adhering particles of magnetite from the pyroxene. The resulting nearly pure pyroxene was recrushed, resized, and passed through the solution again, after which the treatment with the acid was repeated.

ANALYSIS OF PYROXENES FROM VARIETY E. GEO. STEIGER, ANALYST

| | | Molecular Proportion | Diopside | Soda Pyroxene | Alumina Pyroxene | Hypersthene | Quartz |
|---|---|---|---|---|---|---|---|
| $SiO_2$........ | 50.95 | $+TiO_2$ 867 | 408 | 20 | 32 | 351 | 54 |
| $Al_2O_3$....... | 2.72 | 26 | ... | 5 | 21 | ... | .. |
| $Fe_2O_3$...... | 1.70 | 11 | ... | .. | 11 | ... | .. |
| FeO........ | 13.87 | 197 | 69 | .. | 11 | 117 | .. |
| MgO....... | 15.58 | 390 | 135 | .. | .21 | 234 | .. |
| CaO........ | 11.39 | +MnO 204 | 204 | .. | .. | ... | .. |
| $Na_2O$....... | 0.31 | 5 | ... | 5 | .. | ... | .. |
| TiO........ | 1.42 | ... | ... | .. | .. | ... | .. |
| MnO....... | 0.26 | ... | ... | .. | .. | ... | .. |
| Total..... | 98.19 | | | | | | |

To ascertain the relative amounts of hypersthene and augite the following ideal compositions for the two pyroxenes were assumed:

$$\left.\begin{array}{ll} \text{Hypersthene} & (Mg, Fe)O \cdot SiO_2 \\ \text{Augite} & \left\{\begin{array}{l} (a)\ CaO \cdot (Mg, Fe)O \cdot 2SiO_2 \\ (b)\ Na_2O \cdot Al_2O_3 \cdot 4SiO_2 \\ (c)\ (Mg, Fe)O \cdot (Al\ Fe)_2O_3 \cdot SiO_2 \end{array}\right. \end{array}\right\}$$

In the adjustment the $TiO_2$ was regarded as isomorphous with $SiO_2$ and the MnO isomorphous with FeO. A quantity of silica amounting to 3.24 per cent. cannot be accounted for by any probable adjustment, and it may have resulted from decomposition of adhering feldspar after treatment with acid, the insoluble silica remaining behind. In the hypersthene, iron : magnesia as 1 : 2. In the augite, diopside (*a*): soda pyroxene (*b*): aluminous pyroxene (*c*) as 204 : 5 : 32. With this adjustment of molecules the proportion of the two pyroxenes as they occur in the specimen gives:

| | |
|---|---|
| Hypersthene | 38.84 |
| Augite | 56.12 |
| Quartz | 3.24 |
| Total | 98.20 |

Hypersthene is 40.91 per cent. of the pyroxene, and augite 59.09 per cent. of the pyroxene.

Biotite is present as irregular plates, and magnetite occurs as bodies up to 0.8$^{mm}$ in diameter. Apatite occurs as prisms in all the other minerals. The order of crystallization was the same as in D. The chemical analysis of E, taken one quarter-mile west of Mud Lake (see Fig. 3) is as follows:

ANALYSIS OF VARIETY E. GEO. STEIGER, ANALYST

| | | | |
|---|---|---|---|
| $SiO_2$ | 54.09 | $H_2O-$ | 0.20 |
| $Al_2O_3$ | 16.00 | $H_2O+$ | 0.77 |
| $Fe_2O_3$ | 2.92 | $TiO_2$ | 0.99 |
| FeO | 5.54 | $P_2O_5$ | 0.35 |
| MgO | 5.19 | MnO | 0.15 |
| CaO | 7.37 | BaO | 0.10 |
| $Na_2O$ | 3.38 | SrO | 0.06 |
| $K_2O$ | 2.67 | Total | 99.78 |

The norm of E, calculated from the analysis, is given in column I of the following table, the mode in column II.

| I. Norm | | II. Mode | |
|---|---|---|---|
| Quartz | 1.56 | Quartz | 3.7 |
| Orthoclase | 16.12 | Orthoclase | 13.2 |
| Albite | 28.82 | Albite | 26.5 |
| Anorthite | 20.29 | Anorthite | 18.9 |
| Hypersthene | 13.88 | Pyroxene | 28.8 |
| Diopside | 11.22 | Olivine and Serpentine | 0.3 |
| Magnetite | 4.18 | Biotite | 3.1 |
| Ilmenite | 1.98 | Magnetite and Ilmenite | 4.8 |
| Apatite | 1.01 | Apatite | 0.7 |
| Water | 0.97 | Total | 100.0 |
| Total | 100.03 | | |

Variety E is among the most basic of the Haystack rocks, and, according to the quantitative system of classification, is a shoshonose. It is closely similar to a diorite from Rock Creek, Crazy Mountains, Mont., described by Mr. J. E. Wolff,[1] and to a large number of shoshonites from the Yellowstone National Park, described by Mr. Iddings.[2] It is a little lower in potash than these rocks and richer in the ferromagnesian constituents.

### VARIETY F. HESSOSE: OLIVINE-GABBRO

This variety is a dark gray, coarsely crystalline olivine-gabbro which occurs near the center of the stock. The specimen was taken near the base of the cliff southwest of Mud Lake. It is the most basic variety of the stock and is composed of feldspar, pyroxene, biotite, and olivine, the ferromagnesian minerals constituting about two-fifths of the whole.

Under the microscope the texture of the rock is hypidiomorphic granular, and the following minerals, named in relative order of abundance, are present: labradorite, augite, hypersthene, olivine, orthoclase, magnetite, biotite, and apatite. Labradorite occurs as crystals about $1^{mm}$ long, approaching idiomorphism, and is twinned according to albite and carlsbad laws. Orthoclase, containing a little graphic quartz, is present as irregular bodies, filling interstices between other minerals. The pyroxenes occur as anhedra from ½

[1] *Bulletin No. 148*, U. S. Geological Survey, p. 144.

[2] *Journal of Geology*, Vol. III, and *Bulletin No. 168*, U. S. Geological Survey.

to $2^{mm}$ long and include a considerable amount of magnetite and minute particles of olivine and biotite. Olivine occurs as rounded or irregular bodies, in part included in pyroxene. It is partly altered to serpentine which either replaces the olivine completely, or occurs along its cracks. The fibers of the serpentine are parallel and not perpendicular to the boundaries and cracks of olivine. Biotite surrounds magnetite and is partially altered to chlorite. Small irregular grains of magnetite are present, wholly or partially included in the ferromagnesian minerals. The feldspar is almost free from magnetite. Apatite prisms are included in all the other minerals. A small amount of calcite is present.

The order of crystallization is as follows: (1) Olivine, apatite, and some magnetite; (2) some labradorite, pyroxene, more magnetite, and biotite; (3) more labradorite; (4) orthoclase and quartz. An analysis of F, from a specimen taken near the base of the cliff southwest of Mud Lake (see Fig. 3) is as follows:

ANALYSIS OF VARIETY F. GEO. STEIGER, ANALYST

| | | | |
|---|---|---|---|
| $SiO_2$ | 47.87 | $H_2O+$ | 1.25 |
| $Al_2O_3$ | 16.34 | $TiO_2$ | 1.02 |
| $Fe_2O_3$ | 3.59 | $CO_2$ | .44 |
| FeO | 7.17 | $P_2O_5$ | .41 |
| MgO | 7.80 | NiO | .02 |
| CaO | 10.33 | MnO | .14 |
| $Na_2O$ | 2.43 | BaO | .03 |
| $K_2O$ | .92 | Total | 100.04 |
| $H_2O-$ | .28 | | |

The norm of F calculated from the analysis is given in column I of the following table; the mode in column II.

| I. Norm | | II. Mode | |
|---|---|---|---|
| Quartz | 0 | Quartz | 0 |
| Orthoclase | 5.56 | Orthoclase | 4.9 |
| Albite | 20.44 | Albite | 19.2 |
| Anorthite | 30.86 | Anorthite | 26.7 |
| Hypersthene | 12.00 | Pyroxene | 30.9 |
| Diopside | 14.34 | Olivine and Serpentine | 6.8 |
| Olivine | 6.72 | Biotite | 4.5 |
| Magnetite | 5.34 | Magnetite and Ilmenite | 5.8 |
| Ilmenite | 1.98 | Apatite | 1.2 |
| Apatite | 1.01 | Total | 100.0 |
| Water | 1.53 | | |
| Total | 99.78 | | |

Variety F is the most basic of the Haystack rocks, and, according to the quantitative classification, is hessose. In composition it resembles an olivine-basalt from Franklin Hill, Plumas County, California, described by Mr. H. W. Turner,[1] an augite-diorite from Stony Mountain, Ouray County, Colorado, described by Dr. Whitman Cross,[2] and a basalt from Prospect Peak, Yellowstone National Park, described by Mr. Iddings.[3]

*Chemical variation of varieties.*—The analyses of the six varieties are given in the table below. The combining molecules of the rocks which

ANALYSIS OF TYPES OF HAYSTACK STOCK. GEO. STEIGER, ANALYST

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| $SiO_2$ | 65.06 | 64.09 | 57.98 | 54.84 | 54.09 | 47.87 |
| $Al_2O_3$ | 14.71 | 16.20 | 17.01 | 16.41 | 16.00 | 16.34 |
| $Fe_2O_3$ | 2.82 | 2.61 | 3.34 | 3.63 | 2.92 | 3.59 |
| FeO | 1.31 | 2.40 | 3.34 | 4.54 | 5.54 | 7.17 |
| MgO | 2.48 | 2.06 | 2.74 | 4.71 | 5.19 | 7.80 |
| CaO | 3.43 | 4.51 | 7.35 | 6.64 | 7.37 | 10.33 |
| $Na_2O$ | 3.86 | 3.88 | 3.92 | 3.27 | 3.38 | 2.43 |
| $K_2O$ | 3.48 | 2.51 | 2.02 | 2.83 | 2.67 | 0.92 |
| $H_2O-$ | 0.31 | 0.22 | 0.14 | 0.34 | 0.20 | 0.28 |
| $H_2O+$ | 1.10 | 0.44 | 0.49 | 0.93 | 0.77 | 1.25 |
| $TiO_2$ | 0.61 | 0.49 | 0.90 | 0.99 | 0.99 | 1.02 |
| $CO_2$ | ..... | ..... | ..... | ..... | ..... | 0.44 |
| $P_2O_5$ | 0.18 | 0.24 | 0.43 | 0.35 | 0.35 | 0.41 |
| NiO | ..... | ..... | trace | ..... | ..... | 0.02 |
| MnO | 0.18 | 0.09 | 0.12 | ..... | 0.15 | 0.14 |
| BaO | 0.10 | 0.15 | 0.06 | 0.12 | 0.10 | 0.03 |
| SrO | 0.05 | 0.03 | 0.02 | 0.05 | 0.06 | ..... |
| Total | 99.68 | 99.92 | 99.86 | 99.65 | 99.78 | 100.04 |

have been analyzed, arranged according to the increase of silica, are shown in Fig. 2. Silica is platted as the abscissa and 798 combining molecules are taken as an initial point. The alkalies, alkali earths, alumina, and iron are taken as ordinates. The diagram shows graphically the irregularity in the variation of the oxides. Alumina shows little variation, about the same quantity being present in all analyses. Its total range of variation is but 23 molecules. The granodiorite A is least aluminous. None of the oxides vary directly or inversely with alumina, which is higher than any of the

[1] *Seventeenth Annual Report*, U. S. Geological Survey, Part I, p. 734.

[2] *Bulletin No. 148*, U. S. Geological Survey, p. 180.

[3] *Mon. XXXII*, U. S. Geological Survey, p. 438.

other oxides except silica and lime and magnesia, at the basic end of the diagram. Ferrous and ferric iron are in a measure inversely proportional to each other, an increase in one usually being accompanied by a decrease in the other. The total amount of iron decreases irregularly to the more siliceous end of the series. Magnesia also decreases rapidly as the silica increases and this decrease more nearly agrees with that of the ferrous than of the ferric iron. Lime,

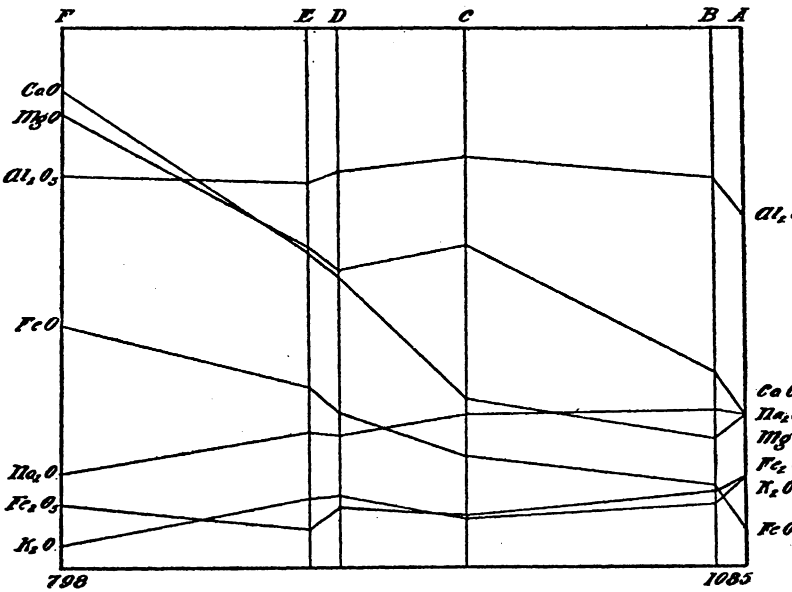


FIG. 2.—Chemical variation of types of the Haystack stock.

like magnesia, decreases steadily from the less siliceous toward the more siliceous end of the series, but increases slightly in the granodiorite at the extreme end. The soda, low in F, increases gradually and steadily to B, and falls slightly in A. Potash increases very irregularly to the more siliceous end of the diagram. The alkalies vary neither directly nor reciprocally with each other, though both increase with silica.

Mr. H. S. Washington,[1] in discussing the differentiated complex at Magnet Cove, Ark., ranges six analyses in order of ascending silica. In his diagram with but one exception the oxides increase

[1] *Bulletin of the Geological Society of America*, Vol. XI, p. 404.

or decrease with the silica. The variations of the oxides in the Haystack series, with respect to silica and to each other, are much less regular than is the series at Magnet Cove. This is well illustrated by the crossing descending lines in the diagram.

*Probable average composition of stock.*—The average composition of the six analyzed varieties of the Haystack stock is as follows:

AVERAGE CHEMICAL COMPOSITION OF THE SIX ANALYZED VARIETIES

| | | | |
|---|---|---|---|
| $SiO_2$ | 57.32 | $H_2O+$ | 0.83 |
| $Al_2O_3$ | 16.11 | $TiO_2$ | 0.83 |
| $Fe_2O_3$ | 3.15 | $CO_2$ | 0.07 |
| $FeO$ | 4.05 | $P_2O_5$ | 0.33 |
| $MgO$ | 4.16 | $MnO$ | 0.11 |
| $CaO$ | 6.61 | $BaO$ | 0.09 |
| $Na_2O$ | 3.46 | $SrO$ | 0.03 |
| $K_2O$ | 2.40 | | |
| $H_2O-$ | 0.25 | Total | 99.80 |

NORM OF THE AVERAGE OF THE SIX ANALYZED VARIETIES

| | | | |
|---|---|---|---|
| Quartz | 8.58 | Magnetite | 4.41 |
| Orthoclase | 14.46 | Ilmenite | 1.52 |
| Albite | 29.34 | Water | 1.08 |
| Anorthite | 21.13 | Fluorine | 0.67 |
| Diopside | 8.51 | | |
| Hypersthene | 10.37 | Total | 100.07 |

This is probably very close to the average composition of the stock, and is perhaps as good an estimate as could be made with the data at hand. Its composition closely resembles that of a large number of orthoclase-gabbro-diorites, andesites, and related rocks from Crandall Basin and Sepulcher Mountains, described by Mr. Iddings,[1] a number of monzonites and andesites from Colorado, described by Dr. Whitman Cross,[2] and diorites from Mt. Ascutney, Vt., described by Mr. R. A. Daly.[3] Of the Haystack rocks the average is nearest C, which is a contact facies of the stock.

*Asymmetry of the stock.*—The map (Fig. 1) shows that the Haystack stock is asymmetrical. The stock is also asymmetrical with respect to its composition. Fig. 3 is a sketch map which shows the

[1] *Mon. XXXII*, U. S. Geological Survey, Part II.

[2] *Bulletins 1* and *168*, U. S. Geological Survey.

[3] *Bulletin 148*, U. S. Geological Survey, p. 69.

location of the rocks analyzed. The most basic (F) is not at the center of the stock, but southeast of it, and the most acid variety (A) is farther from F than the edge of the stock in several other directions. Moreover, the diorite south of F or between F and the border toward the south is less acid than A, though it is much more acid than F. It will hold true, however, that if lines are drawn to the border radiating from F, the composition of the stock along these lines becomes gradually more acid, though at different rates, and

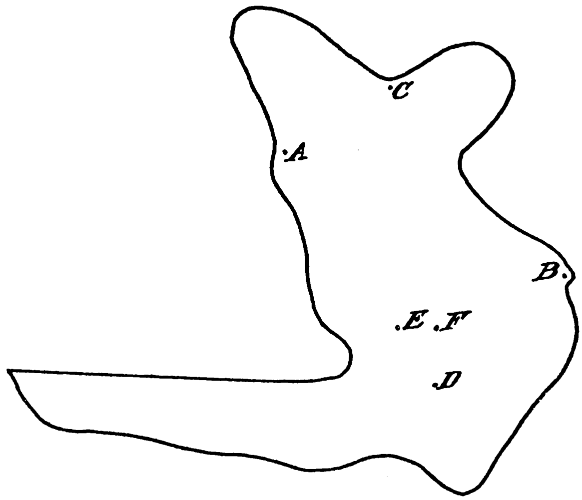


FIG. 3.—Outline of Haystack stock. The letters show the position of analyzed types.

some portions of the periphery are more acid than others. The modes of the six varieties are tabulated below, A, B, and C are the

MODES OF VARIETIES OF HAYSTACK STOCK

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| Quartz | 22.9 | 21.8 | 12.1 | 6.8 | 3.7 | .... |
| Orthoclase | 17.8 | 11.7 | 9.7 | 15.4 | 13.2 | 4.9 |
| Albite | 30.7 | 30.1 | 31.2 | 27.5 | 26.5 | 19.2 |
| Anorthite | 10.3 | 15.1 | 20.8 | 19.7 | 18.9 | 26.7 |
| Hornblende | 9.7 | .... | .... | .... | .... | .... |
| Pyroxene | .... | 11.2 | 13.5 | 19.5 | 28.8 | 30.9 |
| Biotite | 4.2 | 4.8 | 6.7 | 4.6 | 3.1 | 4.5 |
| Olivine and Serpentine | .... | .... | .... | 0.5 | 0.3 | 6.8 |
| Magnetite and Ilmenite | 4.1 | 4.9 | 4.9 | 5.2 | 4.8 | 5.8 |
| Apatite | 0.3 | 0.4 | 1.1 | 0.8 | 0.7 | 1.2 |

peripheral acid varieties, while D, E, and F are the basic central varieties. This table shows that quartz is present in the outer border of the stock in largest amount, and decreases toward the center of the stock. Orthoclase is present in every case, but is most abundant in the facies not far from the periphery. Plagioclase is present in approximately the same amount in all varieties, but is more calcic in the central ones. Pyroxene is least abundant near the periphery, and most abundant in the most basic facies near the center of the stock. Hornblende, in part probably secondary to pyroxene, is relatively abundant only in the most acid portion near the periphery. Olivine is abundant only in the most basic varieties near the center. Biotite and magnetite are fairly uniform in quantity.

The order of crystallization of the minerals of the stock, briefly summarized, is as follows:

1. Apatite, crystallized first, since it occurs in all the other minerals.

2. The ferromagnesian minerals, pyroxene, hornblende, biotite, magnetite, and olivine, crystallized early but mainly after apatite had formed.

3. Plagioclase, crystallized after apatite, after and along with the ferromagnesian minerals.

4. Orthoclase and quartz, crystallized together after plagioclase and the ferromagnesian minerals had formed.

### GRANITE (OMEOSE) VEINS CUTTING THE HAYSTACK STOCK

Granite veins one-half inch to six inches wide cut various rocks of the Haystack stock. These occur at the base of the cliff of the southeast of Blue Lake, on the southwestern slope of Baboon Mountain near the summit, on the wagon road from Cowles to the Yellowstone National Park about two hundred and fifty yards east of the divide in Haystack Basin, and at many other localities. The granite is everywhere from medium to coarse-grained, and is lighter colored than the rock it cuts. The granite is composed of feldspar and quartz with a little biotite and hornblende. The veins do not appear to be persistent in length, since they cannot be traced continuously for any great distance. A specimen from a 2-inch vein cutting a very dark fine-grained quartz-bearing diorite (C) on the southwest slope of Baboon Mountain is a pinkish gray, medium-grained rock.

Under the microscope the following minerals are present in the order of their abundance: alkali feldspar, quartz, andesine, magnetite, hornblende, and biotite. The alkali feldspar is orthoclase, microperthitically intergrown with albite, and occurs as anhedra which reach a maximum diameter of $2.4^{mm}$. Quartz occurs as irregular anhedra of equal size interlocking with orthoclase and sometimes as a graphic intergrowth. A small amount of andesine ($Ab_3$ $An_2$) is present, as slender laths about $0.5^{mm}$ long. These laths are concentrated along the margin of the vein and in many cases their long axes are normal to the contact. Anhedra of magnetite as large as $0.5^{mm}$ in diameter, fibrous green hornblende, and biotite are included in orthoclase and quartz. Biotite is slightly altered to chlorite.

The contact of intruding and intruded rock is sharp in the hand specimen, but under the microscope these two rocks appear to grade into each other within a zone about $0.2^{mm}$ wide. In this zone some of the quartz of the intruding rock appears to have attached itself with similar optical orientation to quartz in the intruded rock. In the crystallization of the veins magnetite, hornblende, biotite, and plagioclase were formed before alkali feldspar and quartz, and the latter two crystallized synchronously. Perhaps all of the minerals, except alkali feldspar and quartz had formed before the intrusion, but if so the magma must have been very fluid, since these minerals do not show flow structure and since the long axes of the plagioclase laths, more frequently than otherwise, make a large angle with the walls.

The composition of the granite veins is not far from that of the micrographic intergrowth of quartz and orthoclase which solidified last in nearly all of the Haystack rocks. The veins were probably formed during the latter stages of the solidification of the rocks they cut, and may represent the liquid portion of the magma after most of the plagioclase and nearly all of the ferromagnesian minerals had crystallized out. Even the smallest veins are very coarse grained and must have cooled slowly. This suggests that they were intruded while the rock which they cut was still hot, or that their water content was sufficiently high to permit the growth of large crystals. The cracks they fill are probably shrinkage cracks formed directly after solidification of the rock.

The mode of the granite is as follows:

| | | | |
|---|---|---|---|
| Quartz | 25.51 | Biotite | 2.78 |
| Alkali feldspar | 60.70 | Magnetite | 3.50 |
| Andesine ($Ab_3An_2$) | 4.09 | | |
| Hornblende | 3.42 | Total | 100.00 |

From this mode the following chemical constitution is estimated:

| | | | |
|---|---|---|---|
| $SiO_2$ | 70.38 | CaO | .75 |
| $Al_2O_3$ | 13.17 | $Na_2O$ | 2.10 |
| $Fe_2O_3$ | 2.74 | $K_2O$ | 7.99 |
| FeO | 1.87 | | |
| MgO | .73 | Total | 99.73 |

From a study of thin sections it is estimated that the alkali feldspar is 15.17 albite and 45.52 orthoclase and that the plagioclase is andesine, $Ab_3An_2$. It is assumed that the hornblende is chemically like that from a quartz-monzonite, at Mt. Hoffman, Colo., and that the biotite is chemically like that from a granodiorite at El Capitan, Yosemite Valley, Cal.

The norm of the granite vein calculated from the estimated composition is,

| | | | |
|---|---|---|---|
| Quartz | 24.50 | Hypersthene | 2.65 |
| Orthoclase | 47.26 | Diopside | .68 |
| Albite | 17.82 | Magnetite | 3.94 |
| Anorthite | 2.78 | Total | 99.67 |

According to the quantitative classification the rock is omeose. In composition it closely resembles a granite from Currant Creek Canyon, Pike's Peak, Colo., described by Mr. E. B. Mathews,[1] a graphic granite from Omeo, Victoria, described by Mr. A. W. Howitt,[2] and a rhyolite from Round Mountain, Rosita Hills, Colo., described by Dr. Whitman Cross.[3] It is not far from the composition of micropegmatite estimated by Mr. J. J. H. Teall from a vein-cutting diabase near Kington.[4]

## GENESIS OF THE ROCKS OF THE STOCK

The gradational character of the various rocks of the Haystack stock shows that it is geologically a unit and should be classed with

[1] *Bulletin No. 148*, U. S. Geological Survey.

[2] *Transactions of the Royal Society of Victoria*, Vol. XXIV, p. 120.

[3] *Proceedings of the Colorado Scientific Society*, Vol. II, p. 33.

[4] *British Petrography*, p. 401.

such bodies as are assumed to have resulted from the differentiation of a single magma. The various rocks must be regarded as essentially of the same age, since they are not separated by sharp contacts, as is the case where an igneous rock is intruded by a later one.

Gradational series of rocks have been recognized and described by a large number of observers. Those who have attempted to explain the phenomenon are in the main agreed that the differences in composition have been brought about through differences of temperature and pressure, or by the direct operation of gravity during crystallization. For some differentiated bodies it is assumed that these processes operated after the homogeneous magma had risen to the place at which the rocks now occur, while for other bodies the magma appears to have been of heterogeneous composition before it rose to its final resting place. These processes have been reviewed comprehensively by Professor L. V. Pirsson, in a recent publication by the U. S. Geological Survey,[1] and to do so here would largely be repetition. Some of them will be briefly stated however and examined not with regard to their general application but with especial reference to the Haystack stock.

*Falling of crystals.*—The simplest theory to account for differences in an igneous body which supposedly was once homogeneous is to assume that, of the minerals crystallizing first, the heavier ones sink, and the lighter ones rise much as the constituent minerals of rocks are separated in heavy solutions in the laboratory. Schweig[2] has made the suggestion that heavy crystals formed in the early stages of rock solidification, fall, and are remelted, thus changing the composition of the magma at different depths. For the operation of the process the viscosity of the magma must not be too great to allow minerals to settle by their own weight. Magnetite, the heaviest mineral in the Haystack stock, was also one of the first to solidify, and it is present in all varieties in nearly the same quantity; consequently at the time crystallization began the magma must have been too viscous for magnetite to fall.

The ferro magnesian minerals, which are much heavier than the feldspars, are most abundant in the central portion of the stock

[1] *Bulletin No. 237*, p. 183.

[2] *Neues Jahrbuch für min. Beil.*, Bd. 17, p. 516.

(D, E, F, Fig. 3), while the feldspars and quartz predominate in the rocks around the border (A, B, C). Variety B, containing 78 per cent. of quartz and feldspars, occurs at approximately the same elevation as F, which contains only 50 per cent. of quartz and feldspar. If differentiation occurred after the magma had reached the place at which the rocks are now exposed it was such that the elements forming the ferromagnesian minerals moved toward the center of the stock rather than downward in the stock. Accordingly the falling of the heavy crystals does not appear to have been an important process after the magma rose to the place at which the rocks are exposed.

*Fractional crystallization.*—Certain intrusive masses appear to have differentiated into rocks of various compositions by simple crystallization during cooling. Since the outer portion of an intrusive body is nearer the colder rocks into which it is thrust, this portion of the intrusive is supposed to solidify first, and the minerals which form first in the rocks would form first of all in the outer zone, and having once commenced to crystallize they would continue to grow while the more soluble constituents would be crowded to the center of the stock. This process, according to Mr. H. S. Washington, accounts for the gradational series of rocks which form the igneous complex at Magnet Cave, Arkansas.[1]

As is shown by the order of crystallization of the minerals (p. 223) quartz and orthoclase formed after the ferromagnesian minerals and plagioclase. If differentiation had been brought about by the process of fractional crystallization, the types in which quartz and orthoclase are present in greater abundance should be the types which were last to form, but the reverse is true if the outer portion of the stock solidified first, for the border varieties A, B, C contain a much larger proportion of quartz and orthoclase and a much smaller proportion of the ferromagnesian minerals than the varieties D, E, F, which occur near the center.

*Fractional crystallization with convection currents.*—According to Becker,[2] gradational series of rocks which constitute certain dikes and laccoliths can have been formed only through fractional crystal-

[1] *Bulletin of the Geological Society of America*, Vol. XI, p. 390.

[2] *American Journal of Science*, 4th Ser., Vol. III, p. 21.

lization with convection currents which during crystallization serve to keep the still liquid central portion of the mass of uniform composition. The least soluble minerals will go out of solution first and these will form around the outer portion of the stock, while the liquid magma inside continues to supply like material which it deposits on the walls as it moves by them. Applied to the Haystack stock this hypothesis is open to the same objections as the one previously discussed for the minerals which are most abundant in the rocks forming the periphyry are those which formed last in all the rock types of the stock.

*Differentiation prior to intrusion.*—Intrusive masses made up of a gradational series of rocks not showing a zonal arrangement across the outcrop are of common occurrence and in most cases they seem to have resulted from differences in the composition of the magma before it came to rest. Mt. Johnson, of the Montenegran Hills, which has been described by Dr. F. D. Adams[1] belongs genetically to the same class, although it is composed of a hollow cylinder of laurvikose inclosing a smaller hollow cylinder of andose, which in turn incloses a cylinder of essexose, the three types grading each into the other. Dr. Adams concludes that before the lava reached its present position, a reservoir somewhere below the mountain had differentiated into a liquid mass of which the heavier portion had the composition of essexose, the upper portion laurvikose, and the central portion andose. The upper portion rising first would form the outer cylinder which in turn would be filled or intruded by andose. Subsequently that would be intruded by essexose. Accordingly the arrangement of the rocks from the bottom up in the earlier body would be the same as that from the center out in the later one. Although the zones are not so well defined in the Haystack stock the rocks of the lowest specific gravity occur near the outer portion of the stock, while the heavier varieties, D, E, and F are near the central portion.

Since no process of magmatic differentiation appears to have operated after the intrusion to form the gradational series of the Haystack stock, it is probable that the differentiation occurred before the magma was intruded and that the basic central portion represents a magma which was erupted after the more acid portion,

[1] *Journal of Geology*, Vol. XI, p. 22.

but that the eruptions followed each other so closely that the magma of one type had not solidified before a magma of different composition rose through it. The resulting rock mass was therefore, a gradational series of rocks rather than a complex of distinctly different intersecting rocks.